

# Electrochemical Investigation of the Influence of an Amine-Based Corrosion Inhibitor on Corrosion-Erosion of Gas Pipelines

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**Abstract**— Gas pipelines are exposed to erosion-corrosion phenomena in production fields. The synergetic effect of fluid parameters (such as velocity, turbulence, fluid regime, etc.) and the characteristics of the corrosion scales formed on the pipe wall can accelerate erosion-corrosion inside oil and gas pipelines. Most of times, injection of corrosion inhibitors (CI) is the only available option to prevent internal corrosion of pipelines. In this study, the influence of an amine-based CI on erosion-corrosion rates, in flowing fluid condition, is electrochemically investigated. The test electrolyte is synthesized to simulate condition of a multiphase gas pipeline. The corrosion rate is measured by Electrochemical Impedance Spectroscopy (EIS) in presence of different concentration of corrosion inhibitor (0, 5, 50, 100 ppm). The dynamic properties of the flowing fluid inside gas pipelines is simulated by means of a cylindrical working electrode with 1200 (rpm) rotational speed. The results showed that in the lack of good adhesion of the corrosion inhibitor films, they could be readily detached from the steel surface by the erosional characteristics of the flowing fluid, exposing the bare metal to corrosive media. This dramatically reduces the life span of the pipeline and causes immature erosion-corrosion failures. The adhesion force of the corrosion inhibitor films are directly related to the thickness of the formed film on the pipe surface and the shear stress generated by flow at the steel surface.

**Index Terms**— electrochemical impedance spectroscopy; corrosion inhibitor, erosion-corrosion, gas pipelines

## I. INTRODUCTION

The growing demand for the natural gas accelerates the attention to the development and optimization of gas pipe network [1], [2]. Pipelines are playing an essential role in all parts of oil industry from production zones to treatment facilities and distribution networks [3]. Failure of any parts of gas pipeline's network imposes drastic costs of repair and/or replacement [4]. This is apart from the costs associated to operation shutdown due to the occurred pipe's failure. Presence of corrosive components such as  $\text{CO}_2$  and  $\text{H}_2\text{S}$  and also aggressive species such as  $\text{Cl}^-$  and  $\text{Ca}^{2+}$  in the water phase cause corrosion of the gas pipelines [5]. Most of the time, the occurred failures in upstream of oil industry, is due to erosion-corrosion phenomena [6], [7].

Flow parameters such as rate (gas, oil, and water), pressure, temperature, etc., along with the pipeline design play important roles in erosion-corrosion processes of gas pipelines. Corrosion products initially precipitate on the pipe surface and can act like a barrier and separate metal from corrosive species. In  $\text{CO}_2$  environment,  $\text{FeCO}_3$ ,  $\text{CaCO}_3$ ,

and/or a combination of them ( $\text{Fe}_x\text{Ca}_{1-x}\text{CO}_3$ ) are the main corrosion product or scale.

For offshore and onshore gas pipelines, injection of corrosion inhibitor is usually the only available option for oil companies [8], [9]. In the past decades, many studies are performed to understand the corrosion behavior of carbon steel pipelines in  $\text{CO}_2$  environments in presence of corrosion inhibitors [10]–[17]. However, a great deal of them dedicated to understand corrosion mechanisms rather than erosion-corrosion mechanisms. Introduction of corrosion inhibitors to the oil and gas pipelines necessitate research to understand their effect on erosion-corrosion processes in flowing conditions. This paper aims to electrochemically investigate the performance of an amine-type corrosion inhibitor (CI), in different concentrations, on the erosion-corrosion of specimens made of API 5L X52 by means of electrochemical measurements (electrochemical impedance spectroscopy).

## II. MATERIAL AND PROCEDURE

The specimens for the electrochemical tests are made of carbon steel API 5L X52 which is a typical material for oil and gas pipelines. The chemical composition of the specimens is presented in Table 1. Theses analysis is based on ASTM E1085 standard. The carbon and sulfur analysis are performed by combustion and infrared detector methods, respectively.

The HRB hardness of the specimens based on cross section is 86. The EIS electrochemical measurements is performed in both static and dynamic conditions. The test electrolyte is synthesized to resemble that of gas pipelines. Table 2 shows the water chemistry of the test electrolyte. The high concentration of aggressive ions such as  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ , and  $\text{Ca}^{2+}$  can be pointed from Table 2. The partial pressure of  $\text{CO}_2$  is 0.53 bar. The electrochemical tests in dynamic condition were performed in room temperature and at a tangential velocity of 146 rad/s (120 rpm).

The concentration of corrosion inhibitor varies from 0 to 100 ppm and the test duration is 25 minutes. In order to avoid formation of microorganisms, a trace amount of anti-bacteria was added to the solutions when contains corrosion inhibitor. An infrared spectrum of the used corrosion inhibitor is illustrated in Figure 1. The graph confirms presence of amine functional group (R-NH-R).

Table1. Chemical analysis of the specimen (API 5L X52)

Element	wt%
C	0.076
Si	0.12
Mn	1.27
S	0.007
P	0.015
Cr	0.016
Mo	0.012
Ni	0.043
Al	0.037
Cu	0.034
Fe	Balance

Table 2. Water chemistry of the test electrolyte

pH	7.2
Ca <sup>2+</sup>	880 mg/l
Cl <sup>-</sup>	9331 mg/l
Mg <sup>2+</sup>	650 mg/l
CO <sub>3</sub> <sup>2-</sup>	4.7 mg/l
HCO <sub>3</sub> <sup>-</sup>	469 mg/l
SO <sub>4</sub> <sup>2-</sup>	94 mg/l
Na <sup>+</sup>	1070 mg/l

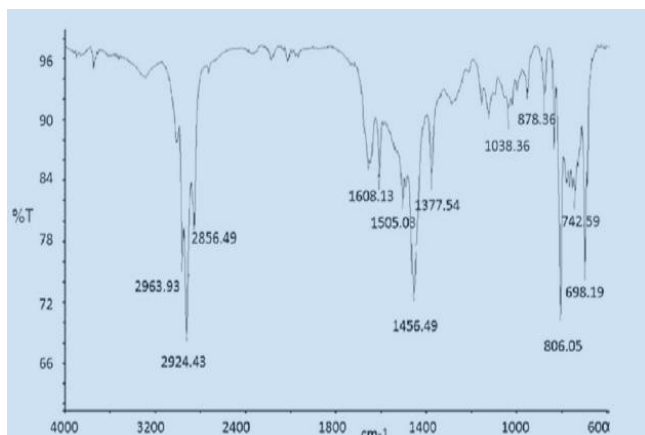


Figure 1. Infrared spectrum of the amine-type corrosion inhibitor

Specimens have a surface area of 5.2 cm<sup>2</sup> in cylindrical shape. A wet grind with 320-grit silicon carbide paper followed by a wet polish with 600 grit silicon carbide paper until previous coarse scratches are vanished. After polishing the specimens were rinse with iso-propanol alcohol and washed with DI water and finally dried with clod air blower. The electrochemical tests performed in a three configuration electrode (working, reference, and counting electrode). The reference electrode was saturated Ag/AgCl and the counter electrode was made from platinum while the carbon steel specimens used for working electrode. CO<sub>2</sub> was purged into the solution to eliminated presence of oxygen and continued during the electrochemical tests.

## III. RESULTS AND DISCUSSION

Figure 2a and 2b show the Nyquist diagram obtained from the static and dynamic test for different concentrations of the corrosion inhibitors. The difference in the level of corrosion rates are related to the difference in the diameter of the rings (semi-cycles) of Nyquist plots of the systems.

The obtained real and imaginary amount of the electrochemical impedance in the static system show that the corrosion rate in the presence of higher concentration of corrosion inhibitor (100 ppm) has increased. Whereas, the lowest corrosion rate obtained at 50 ppm of the corrosion inhibitor present in the solution. The results for the dynamic test were similar to static condition. However, the corrosion rate at the beginning is higher due to different hydrodynamic characteristics of the solutions and thus different mass transfer of the corrosive species to the steel surface.

For both dynamic and static tests, the lowest corrosion rate obtained in the presence of 50 ppm of corrosion inhibitor. It seems that at this concentration, the corrosion inhibitor film, formed on the steel surface, has the highest adhesion force and very resistant to the hydrodynamic forces generated by the flowing fluid. For the dynamic test, in the presence of 100 ppm of corrosion inhibitor, a fragile corrosion inhibitor film on the steel surface was detected. The chemical analysis of this film revealed presence of chlorine and sulfur elements.

The EIS results showed that the adhesiveness of the inhibitor film on the steel surface plays an essential role in the magnitude of corrosion rate. Excess injection of corrosion inhibitor into the pipelines may result in formation of a thicker and less adhesive protective film that can be readily detached from the steel surface by the hydrodynamic properties of the flowing fluid. Removal of the unstable inhibitor film by the flow, exposes the bare metal to the corrosive environment of the pipeline and the electrochemical reactions involved in corrosion process would accelerate in such conditions. Indeed, the unprotected area of the steel surface acts like an anode zone in compare to the covered zones. A small area of anode coupled with large cathode area means fast dissolution of anode which results in localized corrosion.

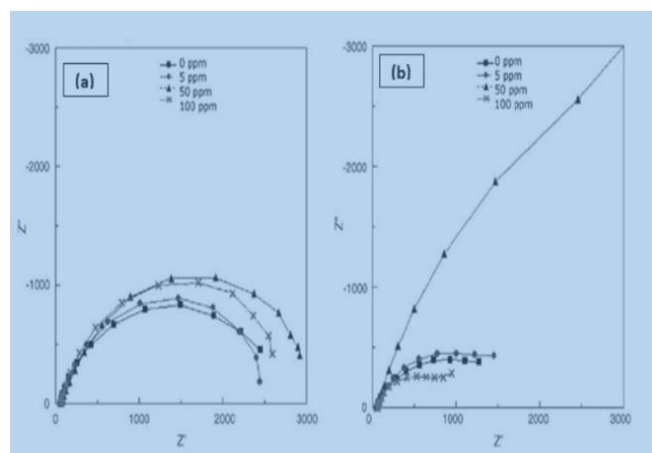


Figure 2. Nyquist plots for different concentration of the amine-type corrosion inhibitor (0, 5, 50, 100 ppm). (2a) corresponding to static tests and (2b) related to dynamic tests (1200 rpm)

#### IV. CONCLUSIONS

□ Based on EIS measurements the optimum concentration for the studied corrosion inhibitor for both dynamic and static condition is 50 ppm. At this concentration, the formed film on the steel surface has the highest resistance to the corrosive environments.

□ At 50 ppm of the amine-based corrosion inhibitor, the most stable organic film on the steel surface formed. This passive layer had the optimum thickness and the resistance to the erosional properties of the flowing fluid.

□ The injection of 100 ppm of corrosion inhibitor resulted in precipitation of a thick and unstable layer on the steel surface. In this condition, the surface layer can be removed by the flowing fluid and exposed the bare metal to the corrosive media.

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